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Perspective

Exploring perceived impacts of onshore wind farms and the link to public support and experience

Leanda Vedder [a,*], Karlijn van den Broek [a,b], Martin Junginger [a], Luis Ramirez Camargo [a]

[a] Copernicus Institute of Sustainable Development, Utrecht University, the Netherlands
[b] Research Centre for Environmental Economics, Heidelberg University, Germany

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ABSTRACT

The perceptions of wind farm impacts play a key role in shaping local support for wind farms. However, previous research has not examined the prevalence of impacts most salient in public perceptions, and acceptance of impacts is often studied in isolation, focusing on single or limited types of impacts. To address this gap, we (1) reviewed the literature to identify commonly researched impacts, (2) conducted a multi-country European survey (n=356) to determine people's perceptions of the impacts and the relevance of the impacts identified in multidisciplinary literature, and (3) examined how these perceptions relate to previous experiences with wind farms and level of support through logistic regression analysis. We identified sixteen impacts from the literature. Through a thematic analysis, 17 additional impacts emerged from participants' descriptions. All 33 impacts were classified into four themes: social, environmental, economic, and energy production-related. Impacts from the literature were consistently rated moderately to highly relevant. The results show that both support for and experience with wind farms shape which impacts were reported. Opponents were more likely to emphasise social and environmental impacts, whereas supporters frequently referenced impacts associated with energy production. Respondents with prior experience reported more social, environmental, and economic impacts than those without. This study contributes to linking the understanding of wind farm impacts with acceptance research, highlighting the need to integrate these perspectives. A holistic consideration of impacts across scientific domains may support future research on public acceptance and contribute to more effective decision-making in wind farm development.

1. Introduction

Wind energy is an important cornerstone for the energy transition in the EU, considering climate change mitigation, energy security and independence in light of ongoing political and social concerns such as the war between Russia and Ukraine [1]. Although wind energy generally enjoys strong public support, acceptance at the local level often depends on whether the adverse impacts of wind farms are prevented, compensated for and tolerated, and to what extent the local context is taken into account [2]. Onshore wind farms remain particularly highly controversial due to the wide range of ecological, economic, and technical challenges that raise public concerns [3]. In general, the positive public attitudes towards wind energy stand in stark contrast with attitudes towards local wind farms [4]. Consequently, the acceptance towards local wind farms has been found to be shaped by attitudes towards their impacts [5].

Theory on sustainable energy technology highlights how perceptions of technology impacts shape acceptance of the technology. A framework by Huijts et al. [6] based on a literature review of sustainable energy technology acceptance suggests that support hinges on the technologies' perceived outcomes, such as perceived costs, risks and benefits, which shape attitudes, which in turn, shape intentions to act in favour of (or against) the technology. Individuals weigh the perceived costs, risks and benefits and choose the option with the highest benefits against the lowest risks or costs [6]. Further, they use moral evaluations to assess the perceived positive and negative impacts on nature and society and relate them to feelings of satisfaction, joy, fear or anger towards the technology [6–8]. Attitudes are additionally shaped by expectations about future wind farm impacts [9]. Together, these processes result in attitudes about the effects or consequences of a wind farm in operation. Therefore, perceived impacts can be defined as the expected and experienced impacts of wind farms. The perception of wind farm impacts

* Corresponding author.
E-mail address: l.vedder1@uu.nl (L. Vedder).

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forms the foundation for local acceptance or support for wind farms [10].

Besides perceived impacts, local stakeholders' support for specific siting decisions is often grounded in how potential negative impacts are defined, communicated and managed and how fair they are perceived as [7], whereby preventing, mitigating or compensating adverse project impacts determines community acceptance [2]. Support was also found to be affected by trust in involved actors and was indirectly shaped by perceived costs, risks and benefits [6]. Understanding public perceptions of emerging energy technologies can facilitate communication between stakeholders and generate acceptance for a project, at the same time, the public can be unwilling to support a new technology due to a lack of familiarity, knowledge and salience on energy technologies, especially in early stages of development [11].

Experience is another mechanism influencing how people weigh factors to come to an opinion or intention to act towards a technology, as experience can increase knowledge and influence perceived costs, risks and benefits [6]. Awareness and certainty about impacts have also been found to predict support for wind energy, where understanding complex public perceptions of wind farm impacts facilitates acceptance and meaningful engagement [12]. Exposure to wind farms leads to reporting of more positive impacts of wind farms [13]. Assessments before and after the construction of a wind farm show that negative impacts are perceived as higher before construction than the perception of the experienced impacts later on, after experience with the wind farm [14]. Hence, the relationship between perceived impacts and experience with existing wind farms warrants further investigation.

Ample research has examined the impacts of wind energy and its implications for public acceptance [15,16]. Much of the research on perceived impacts of wind energy focuses on small-scale case studies [5,16,18]. Beyond that, research on a national scale, such as on the impacts of wind energy in France [20] or on the visual impacts of the existing US wind turbines [21], has been conducted. Previous studies concentrate on closely related groups of impacts and explore the role of these impacts on shaping wind farm support and opposition. For example, landscape impacts such as changes in the aesthetic value of landscapes resulted in opposition to renewable energy [22], whereas economic benefits increase the support for wind energy [14]. Despite this extensive body of research, the perception of wind farm impacts, support and experience with wind farms are rarely examined together. Studies that combine these perspectives often focus on specific phases during the project lifetime [23]. However, integrating impact perception, acceptability and experience is essential for understanding how to facilitate the realisation of new wind farms. We build on previous research in this exploratory perspective paper, applying a cross-disciplinary assessment of what wind farm impacts people envision, and relating it to people's experience and support.

For this purpose, we explore the following research questions:

1. Which impacts of onshore wind farms are most salient in public perceptions across European countries, and do they differ from the impacts most commonly emphasised in the literature?

   1.1. Which impacts are mentioned in connection with the perception of wind farms in the literature? How do they compare to the perceived impacts mentioned by citizens and stakeholders?
   1.2. Do perceptions of wind farm impacts influence individuals' support for wind farms?
   1.3. Do perceived impacts differ depending on individuals' prior experience with wind farms?

We conducted a scoping literature review followed by a survey across multiple European countries to capture various landscapes and levels of wind farm deployment. In this way, we expect to contribute to the development of a more holistic approach to investigate and generate a cross-disciplinary overview of wind farm impacts. Moreover, we link acceptance and impact research by assessing the connection between different impacts with the level of experience and support for wind farms. This work is intended as a conceptual contribution that advances a more integrated understanding of wind farm impacts, which can enhance future investigations into public perception or acceptance and support informed decision-making processes for wind farm projects.

2. Method

We employed a mixed methods approach to achieve a balanced understanding of relevant wind farm impacts by combining a literature review with a survey that provided both quantitative and qualitative data (Fig. 1). First, a scoping review was conducted to establish a comprehensive collection of actual and perceived wind farm impacts from current research. This type of review is a practical tool for topics characterised by strong heterogeneity [24], as is the case here due to the different disciplinary approaches and nature of impacts. Next, the identified wind farm impacts were fed into a survey that explored perceived wind farm impacts among European citizens and wind farm stakeholders.

2.1. Scoping literature review

The aim of this scoping literature review is to provide a comprehensive overview of key impacts of wind energy that may influence public support or opposition. We sourced both social and natural sciences papers from the journal search engines Scopus and Web of Science, written in English and published until October 2023. We narrowed the focus to peer-reviewed literature reviews and articles discussing multiple impacts accessible to the authors through institutional accounts. To maintain a broad overview, we excluded articles on single impacts, as they are often discipline-specific and highly detailed. We accept potential amplification of impacts that arise from the inclusion of the same publications in different literature reviews, as this indirectly discloses which impacts are attracting increased attention in research. To extract information, we utilised a literature review synthesis matrix including main findings, methodology, limitations, future research directions, and mentioned wind farm impacts.

2.1.1. Screening process and data extraction

During the screening phase, we applied three main inclusion criteria: (a) articles explicitly investigating wind farm impacts, (b) papers on reactions to wind farm (impacts), including acceptance and resistance and (c) consequences of wind farm impacts. To enable a comprehensive overview, we applied the search terms listed in Table 1, where tertiary terms serve as complementary rather than synonymous concepts to include both the impacts of wind farms and the involvement or responses of people towards potential impacts. Emphasis was placed on onshore wind energy as we assume that people are more easily exposed to and conscious of the impact of onshore wind turbines. Offshore studies were included if their impacts were cogitable in an onshore setting. Gonyo et al. [12], for example, discussed perceived impacts of a nearby offshore wind farm, such as altered views, habitat loss, and economic effects, which we deem comparable to those in an onshore setting. Furthermore, "cooperation" and "stakeholder" were included as search terms to cover articles on actions on wind energy and community acceptance. The applied exclusion criteria were: (i) articles that focused on technical advancement and airborne wind turbines, (ii) articles on the impact of wind energy in combination with fossil fuels and (iii) articles on impacts of wind energy as a supply for other facilities or energy sources. These exclusion criteria were applied to avoid a focus on the impacts of technological progress or the decarbonization of industries.

The initial search of the databases yielded 76 potentially eligible records, of which 13 were selected for full-text screening based on the inclusion and exclusion criteria. Three additional records were identified through backwards and forward snowballing and the inclusion of

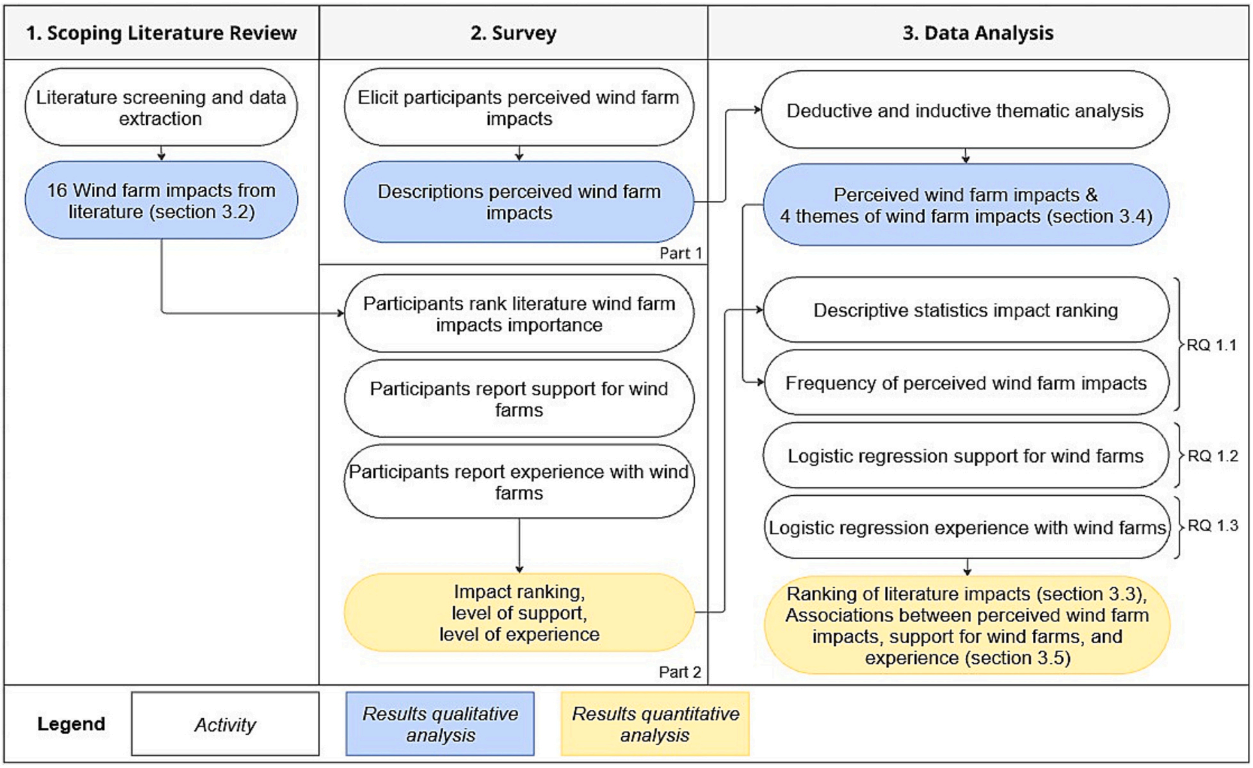

Fig. 1. Graphical representation of the research design outlining activities and results of the scoping review, survey and data analysis.

Table 1
List of key terms on wind farm impacts and acceptance.

Primary term	Secondary term	Tertiary term
wind	energy	impact
	power	effect
	farm	accept*
	park	oppos*
	onshore	approv*
		cooperation
		permission
		resist*
		stakeholder
		collabor*
		particip*

relevant online preprints. This resulted in a final sample of 16 articles (full list in Supplementary material E). In the first cycle, we mapped out impacts from the selected articles and categorised them under environmental, economic, and social factors; in the second cycle, we noted how frequently they occurred. These impacts served as input for the subsequent survey.

2.2. *Survey on wind farm impacts*

An online survey was conducted using Qualtrics to (1) elicit the most prevalent wind farm impacts people could think of, and (2) rate the predefined wind farm impacts from the literature review according to their perceived relevance. We targeted the general public and wind energy stakeholders in Austria, Italy, the Netherlands, Norway, and Portugal, a country selection with varying levels of wind farm deployment and landscapes. The English survey was translated into Dutch, German, Italian, Norwegian (Bokmål), and Portuguese, and revised based on feedback from native speakers and researchers (English version in Supplementary Material A).

2.2.1. *Materials and procedure*

The survey began by introducing participants to the topic of wind farm impacts, which we define as the effects or consequences, positive or negative, that the development and operation of a wind farm can have. First, we inquired about their previous experience with wind farms by asking if they or their family live or have lived close to a wind farm. After that, we asked them to rate their familiarity with wind farm impacts on a 5-point rating scale (1= *not at all familiar*, 5= *extremely familiar)*. Participants were invited to list up to five wind farm impacts they expect or have experienced. This open-ended question preceded the presentation of literature-based impacts, allowing for an unbiased comparison between participants' own descriptions and established impacts. Then participants rated the wind farm impacts identified in the literature review according to their perceived relevance on a 7-point rating scale (1= *not at all relevant*, 7= *extremely relevant*). Participants then indicated their support for wind energy on a slider scale ranging from 100 (support) to 0 (opposition). The question was deliberately phrased in an open-ended manner, without distinguishing between the local and national scales, in order to allow participants to choose their natural cognitive frame of reference and to avoid an artificial separation of attitudes that are likely to be intertwined. For this reason, participants' perceptions may reflect different frames of reference. The final section of the survey collected demographic information and requested participants to self-identify with relevant stakeholder groups in the context of wind farm development.

2.2.2. *Participants and recruitment*

Participants were reached through two consecutive rounds of data collection. The recruitment strategy aimed to reach a cross-section of backgrounds to include different levels of wind farm knowledge, as well as support and opposition in our sample. During the first round, participants were contacted by sharing the survey with a convenience sample of European citizens through snowball sampling. They were reached via social media posts on LinkedIn and by inviting participants to share the survey in their personal social circle. Stakeholders were recruited through a network of wind energy experts involved in Horizon Europe projects. This was complemented by outreach to sceptical stakeholders in all five countries, including associations, community groups, and NGOs, who distributed the survey within their networks. In the second round, we supplemented the data with participants with a more representative education level via the online panel platform Prolific, since the sample of European citizens was biased towards higher education in our sample. The participants included via Prolific were compensated for their participation. Since the survey took little time and the compensation was set appropriately for the effort involved, we consider the risk that the compensation could have affected the reliability of the results to be low.

2.3. Data analysis

The open question text responses were analysed by the first author through a mix of deductive and inductive thematic analysis following the guidelines on conducting thematic analysis by Braun and Clarke [25]. First, a deductive or "theory-driven" approach was applied, where codes were predefined based on the findings of the literature review. (Supplementary material B). Semantic coding, which refers to a descriptive analysis of the input from the participants, was employed [26]. Second, an inductive approach was applied to code additional impacts that emerged during analysis that did not fit the codes developed through the deductive coding process. As interdisciplinary researchers on wind energy, we approached the thematic analysis with awareness of how our prior knowledge and academic training in the European context shape how the descriptions of participants are interpreted, while deliberately remaining open to meanings emerging from participants' accounts and treating impacts as situated, contested, and multiple rather than fixed truths. When responses were ambiguous, we used multiple codes if applicable or created broader umbrella codes. For example, we used the term environmental effects when impacts on nature were mentioned without further detail. All impacts that did not fit in the deductive codes were first collected under the term "Other". From there, we assessed if the description reoccurred and created a new code if it was mentioned in more than one response.

The four themes for the data analysis are based on categories developed in previous relevant literature, e.g., McKenna et al. [15] and Rand & Hoen [16], to discuss different impacts. Similarly, Hübner et al. [27] created comparable categories in their integrated acceptance model. Following a deductive coding process, we arrived at fewer different themes, as the responses did not provide enough detail to form more fine-grained themes, while remaining aligned with the overarching topics present in the literature. The aggregation of perceived impacts into four themes balances the detail-oriented descriptions of the perceived impacts and provides conceptual clarity for the quantitative analysis, and reduces the role of different levels of salience of perceived impacts within our sample.

For the quantitative part of the survey, we used logistic regression analysis to explore potential relationships between support for wind energy, as well as previous experience with wind energy and the reported impacts. The first logistic regression was performed with support as the dependent variable, representing respondents' support for wind energy. The independent variables included the four themes of perceived social impacts, environmental impacts, economic impacts, and energy production impacts. In this way, we aimed to identify which types of perceived impacts significantly influence the likelihood of supporting wind farms. The second logistic regression was performed with experience as the dependent variable and the four impact themes as independent variables to determine which perceived impacts are linked to having direct experience with wind farms.

3. Results

3.1. Sample description

A total of 448 potential participants accessed the survey link, leading to 356 completed responses. We reached 256 participants via snowball sampling, 100 participants (25 each from Austria, the Netherlands, Norway, and Portugal) were recruited through the online panel portal. The final sample consisted of participants aged between 17 and 83 years (M=37.62, SD=14.45), with 42% female, 56% male, and 2% identifying as other. A relatively balanced sample was achieved across the target countries: Austria (n=59), Italy (n=78), the Netherlands (n=58), Norway (n=58), and Portugal (n=37). An additional 52 responses came from other European countries, including Germany, Belgium, the UK, and Switzerland. Support levels ranged across the full scale (M=61.42, SD=36.03), with a tendency toward the extremes, likely due to the sampling strategy targeting individuals with wind energy expertise or critical perspectives (Fig. C.1, Supplementary Material C). A broad range of experiences with wind farms and personal involvement was captured. Overall, 203 participants (57%) did not live close to a wind farm and therefore had no experience with wind farms, 55 (16%) lived close to a wind farm and therefore had direct experience, and 101 (28%) had friends or family living near one and therefore had indirect experience with wind farms. While less than half reported direct experience, the majority rated themselves as familiar with wind farm impacts (M=3.21, SD=1.21) on a scale from 1 to 5. Participants described a wide range of impacts, with 4.07 (SD=1.86) impacts on average and 33 different impacts overall. A detailed sample description and breakdown of stakeholder groups represented in the sample can be found in the Supplementary Material C.

3.2. Wind farm impacts in literature

We created a multidisciplinary overview of wind farm impacts, representing a broad collection of factors deemed relevant for wind power deployment. The reviewed papers cover a range of social, ecological, economic and environmental impacts (Table 2).

3.3. Ranking of literature impacts

All impacts reported in the literature are perceived as moderately to highly relevant by the survey participants, with mean values ranging between 3.90 and 5.00. Visual landscape disruption received the highest average rating with a mean value of 5.26 (SD= 1.72) (Fig. 2). Closely following are land use change (M= 4.99; SD= 1.67) and wildlife

Table 2
Wind farm impacts identified in the literature review, with percentages indicating the share of studies that mention each impact.

Impact	Share of reviewed papers (N=16) reporting each impact
Visual landscape disruption	75 %
Noise pollution, noise emission	50 %
Animal fatalities	50 %
Wildlife disturbance	44 %
Climate change	44 %
Economic benefits	44 %
Land use change	38 %
Health risks	31 %
Property values	31 %
Electricity rates	25 %
Shadows and shadow flicker	19 %
Job creation	18 %
Deforestation	13 %
Local change in surface temperature	6 %
Soil Erosion	6 %
Agricultural productivity	6 %

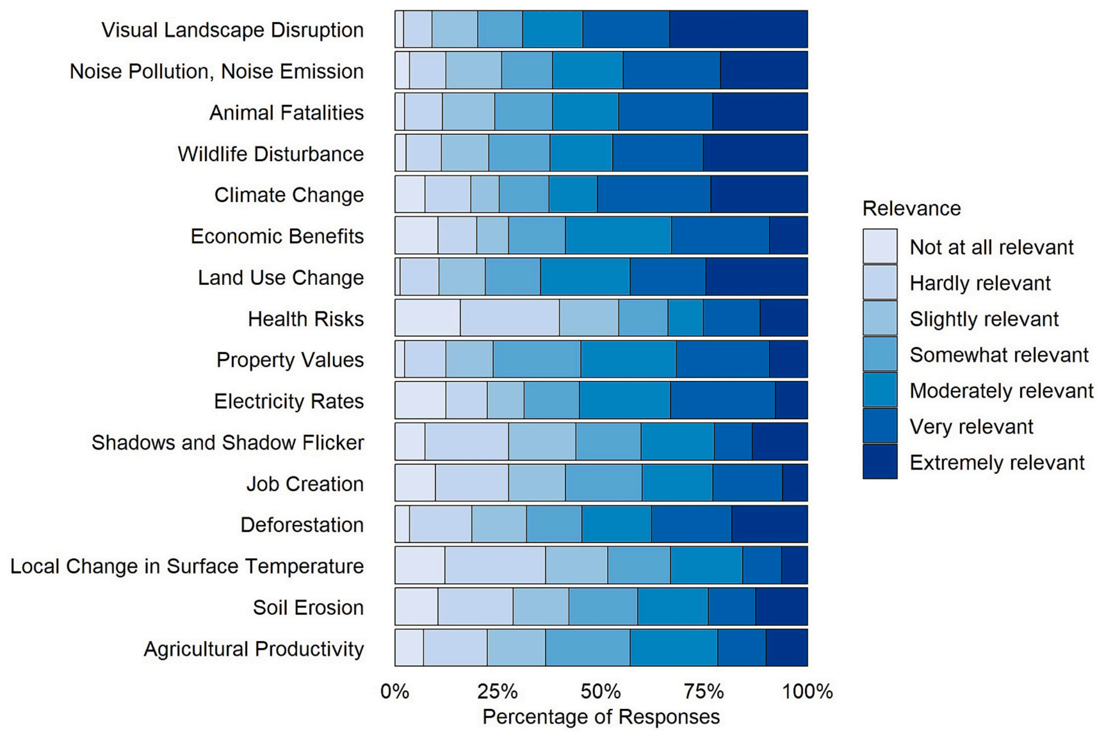

Fig. 2. Stacked bar chart showing the distribution of perceived relevance ratings for potential wind farm impacts (1–7 rating scale, from "not at all relevant" to "extremely relevant").

disturbance (M= 4.99; SD= 1.74). Conversely, surface temperature change was ranked lowest with a mean value of 3.55 (SD= 1.77), followed by *health risks* with a mean of 3.61 (SD= 2.01).

3.4. Perception of wind farm impacts and their importance from the open survey question

A broad range of perceived wind farm impacts salient to the public across scientific domains was represented in participants' elaborations. Following, we discuss their responses in light of current literature. From

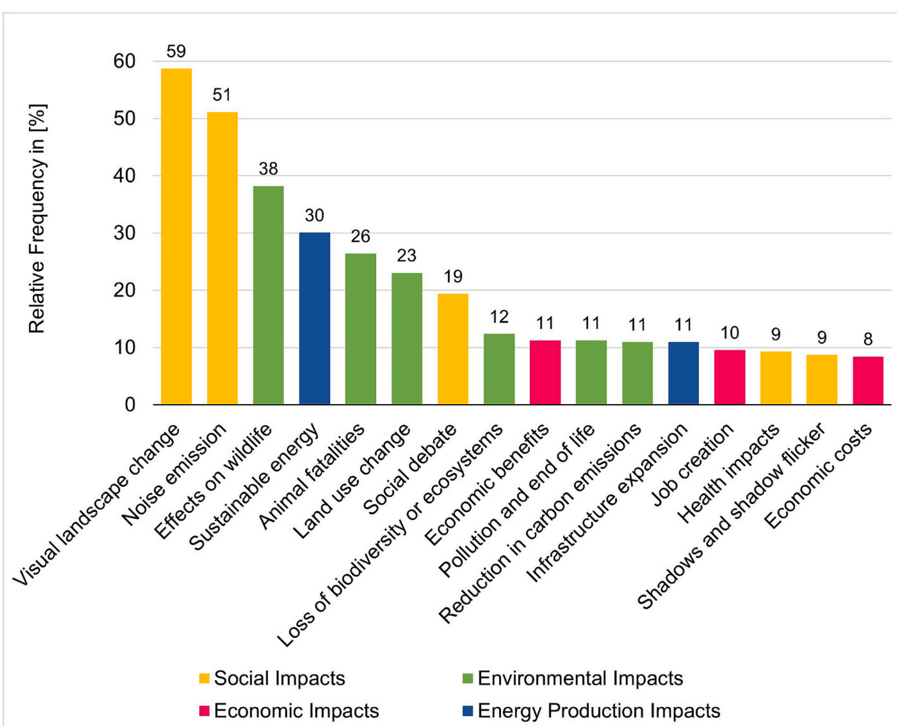

Fig. 3. Wind farm impacts identified by survey participants grouped by themes. Impacts mentioned less than 30 times are not presented in the figure.

the thematic analysis, four overarching themes emerged, namely "social impact and effects on individuals", "impacts on the natural environment", "economic effects" and "energy production and wind farm properties". No single impact theme dominates the perceptions, as all themes are represented when looking at the most mentioned wind farm impacts (Fig. 3), indicating that there is no strong association of wind farms with only one specific theme. In the following, perceived impacts reported by participants appear in *italics*, whereas those discussed from the literature are shown in regular font.

The most frequently reported perceived impacts were *visual landscape change* (59%), *noise emissions* (51%) and *effects on wildlife* with 38%, followed by *sustainable energy* (30%) and *animal fatalities* with 26% (Fig. 3). C*limate change (3%)*, *ice throwing* (3%), *deforestation* (3%), *marine impacts* (1%), and *change in surface temperature (*1%) were the least mentioned. We found pronounced overlap between impacts discussed in literature, e.g., visual landscape change, land use change and wildlife disturbance, which were also frequently mentioned in response to the open survey question, showcasing high sensitivity of research regarding these impacts. Interestingly, impacts such as *climate change* and *change in surface temperature* were rarely described in the open survey question, yet received high scores in the ranking question on the relevance of impacts from the literature. Beyond that, the open survey question surfaced descriptions of impacts such as, e.g., *sustainable energy* or *social debate,* etc., that point to further nuances in perceptions of wind farm impacts, which can be expanded on in research.

3.4.1. Theme 1: Social impact and effects on individuals

The first theme contains perceived impacts related to the social factors, as well as impacts on the individual human being. The two most mentioned impacts, *visual landscape change* and *noise emission* (Fig. 3), fall within this category. Other impacts clustered under this theme are *health impacts* (9%) expressed as e.g. "Damage to health", "Nervous tension" or "Disturbed sleep", *shadows and shadow flicker* (9%) and *blinking lights* (3%). Visual landscape change is considered to be one of the most common conflict issues with regard to wind farm development, and the evaluation of the impact on the landscape is a dominant factor explaining support or opposition to wind farms [15,28,29]. Resistance to wind turbines decreases with experience with turbines and can be dependent on the socio-cultural background of the country [30,31]. Frantál et al. [28] synthesised the findings from multiple studies showing that negative perceptions of noise, shadow flicker, and uncertainties about health risks persisted even years after the wind farms were constructed. Obstruction lights flashing were found to influence annoyance stress levels, but were dependent on technical and site-specific conditions [33]. Furthermore, the actual exposure to shadow flicker in most European countries is limited due to guidelines or standards that do not allow more than 30h/year in the worst-case scenario [34]. Another impact emerging in Austria and Norway was *ice throwing from the turbine blades* (3%), which was considered a danger to human health, e.g. "Dangerous ice falling" or "restriction of area access due to icefall in winter".

Two social impact topics emerged from the survey data that were not represented in the impacts listed from the literature review. The social dynamics surrounding wind farms were clustered as *social debate* (19%), which includes a range of descriptions related to ongoing debates within a community ignited by existing or potential future wind farms, e.g. "Debates comparing wind farms to other energy sources", "Divides local communities", " Polarisation of society" or "Concerns of local people". Furthermore, this impact incorporates positive and negative positions towards wind farms, e.g. "Proudness among citizens", "Need for public support", "Community Engagement" or "Resistance citizen initiatives", that drive debates. Our survey results suggest that participants perceive the *social debate* on wind farms as an ongoing process rather than one that concludes once the wind farm is deployed, as both people with and without experience with wind farms recounted this impact. This is also reflected in concerns about persistent misunderstandings, such as the statement, "There is a lack of understanding because not all turbines are turning." These reactions are fuelled particularly by the announcement of new plans or decision-making on the future of existing wind farms, which further illustrates how *social debate* can be understood as an impact of wind farms.

Another emerging impact was *Justice for local (indigenous) communities* (6%) expressed as "Impact on minorities", "Historical and cultural identity" and "Impacting indigenous communities' livelihood". Especially, responses from Norway included justice-related aspects for indigenous communities. Specifically, the effects of wind farms on reindeer farming of indigenous communities are contentious and a focus of research [35,36]. In literature, the social perception is discussed predominantly with a focus on attitudes towards new wind farm projects during the planning phase. The wind farm proposal phase was identified as crucial for engaging with communities [37], where research set a focus on social acceptance, including trust and stakeholder engagement [10,29,38]. Research calls for more studies on the perception of existing wind farms and residents around them [16]. The dimension of justice in planning seems to be related to the perception of impacts, as Hübner et al. [39] found that the experienced planning process was related to stress from wind turbine noise. Further, justice dimensions of wind energy are increasingly understood as relevant to local wind farm development [14,40].

3.4.2. Theme 2: Impacts on the natural environment

The second theme evolves around different impacts on the natural environment, such as *effects on wildlife* (38%), depicted as negative impacts like "Disturbing wildlife", "Destroying grazing areas" or "Fragments habitats", but also neutral statements like "They do not have a direct impact on the local fauna" and even benefits like "wildlife preservation". *Animal fatalities* (26%) include explanations such as "Birds get hit by windmills" or "Collisions with propeller blades". A range of impacts was mentioned only a few times, such as *soil erosion* (4%), *(mitigating) climate change* (3%), *deforestation* (3%) and *local change in surface temperature* (1%). Also, the *reduction of carbon emissions* (11%) was considered an impact of wind farms. The strong focus on environmental impacts aligns with research that shows both supporters and opposers of wind farms basing their reasoning on environmental concerns [16]. Surprisingly, soil erosion, climate change and deforestation all scored high mean values in the question on relevance of different impacts (Fig. 1), which indicates a discrepancy between the salient impact and the perceived relevance of the impacts. In addition, the worry about *loss of biodiversity and ecosystems* (12%) was prevalent, and effects of end-of-life scenarios and *pollution* after use were discussed (11%). Participants mentioned "Loss of untouched nature", "Weakened ecosystems", or simply "Loss of biodiversity". We did not find a specific description of the impacts of wind farms on biodiversity loss in literature, but rather effects on wildlife behaviour and habitat suitability due to changes in land cover [30,41]. There, land-use change impacts were found to be broad and regionally diverse [42]. Furthermore, there were some location-specific impacts such as *hydrogeological or geological impacts* (4*%)* depicted as "Geological stability" or "Heavy impact on the hydrogeological environment*"* and *marine impacts (1%),* e.g. "Inference in the life cycle of marine species" and "Impact on marine substrates", that were mentioned mainly by Italian participants. Several respondents (7%) mentioned impacts on the environment or nature, but did not expand on exactly what was referred to with this description.

3.4.3. Theme 3: Economic effects

In the survey responses, *economic benefits* (11%) were generally mentioned as "Local investment", "Bringing money to the municipality" or "Alternative income", but also more specific descriptions, such *as job creation* (10%) and *electricity price reduction* (7%) were mentioned. *Economic costs* (8%), such as "Cost-intensive construction" and "Operating costs", were outlined as well. Another effect on *agricultural productivity* (6%) was mentioned as "Consumption of fertile agricultural land" and

“Damage to agriculture”. Perceived economic impacts are driving factors for acceptance of wind farms for people affected by existing or proposed wind farms [16]. Adequate economic benefits were found to be a key factor to counterweigh other impacts of wind farms [14]. An impact that received less attention compared to the literature was *changes to property values* (4.%). Real estate values showcase a range of positive and negative changes in recent literature [15]. The diversity of impacts on property values and local job creation results in the need for further research [15]. Another economic impact that came up was the *effects on tourism and recreation* (3%), explained by “Destroyed outdoor recreation areas” or “Losses in tourism”. The effect on tourism was predominantly mentioned by participants in Austria, such as “Competition with recreation and tourism”. In an Austrian study, the acceptance of wind farms in the Alps was slightly lower than the general acceptance of the technology, still, no opposition to wind farms was recognized among tourists [43]. Economic impacts were less frequently mentioned in the open-ended responses compared to social and environmental impacts. The impact *economic benefit* received consistently positive ratings in the ranking question on impact relevance and is frequently thematised in the literature.

3.4.4. Theme 4: Energy production, infrastructure and energy independence

Theme four emerged from the survey responses and describes energy production and wind farm properties, which are considered impacts of wind farms. Especially the generation of *sustainable or green energy* (30%), described as “Fossil-free”, “Green” or “Clean energy”, was considered a direct impact from wind farms. We did not encounter this perspective in literature, which we attribute to the differentiation between the intended purpose and impact of wind farms. The *reduction in carbon emissions*, as discussed in the section on environmental impacts, was often mentioned together with sustainable energy, indicating the understanding of the interrelation of these two concepts. *Infrastructure expansion* (11%) in relation to the integration of wind farms into the grid was mentioned, e.g., “Expansion of the power grid”, but also regarding the construction of “Access roads and cabling”. Moreover, wind farms were seen as a means of *energy independence* (3%), expressed as “Increased energy autonomy”, “Reducing dependency on fossil fuels” and “Energy Self-Sufficiency”. Beyond the impacts described, we identified additional factors that were frequently mentioned, which could be more accurately characterised as descriptions of wind farm properties, such as the *size of the wind farm* and *turbine design* (both 6%). We include these factors here as attributes of infrastructure, but are aware of the interplay with the impact of *visual landscape change* from theme 1.

3.5. The influence of wind farm impacts on attitude towards wind farms and experience

Participants recognised similar impacts within the 4 themes, however, the frequency of the different impacts mentioned varied according to their support for and experience with wind farms. Firstly, a logistic regression was performed to ascertain the effect of social impacts, environmental impacts, economic impacts and energy production impacts on participants’ support or opposition to wind farms, where the model was statistically significant, with a X2 (4, N=356) =45.68, $p < .001$. The results of the logistic regression indicate that opponents of wind farms are more likely to mention the social and environmental impacts of wind farms, while supporters are more aware of the energy production impacts of wind farms, as illustrated by the relative frequencies of accumulated impacts reported across the four themes by supporters and opponents (Fig. 4). The confidence intervals of the odds ratios were 0.62 times lower for mentioning social impacts (95% CI [0.49, 0.78]) and environmental impacts (95% CI [0.49, 0.77]) for participants supporting wind farms in comparison to participants who oppose them. The confidence intervals of the odds ratios for impacts related to energy production were 1.47 times higher (95% CI [1.01, 2.16]) for participants supporting wind farms (full regression results in

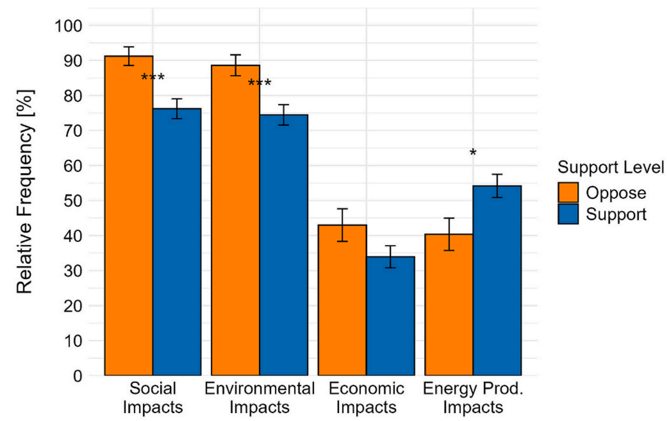

Fig. 4. Relative frequencies of wind farm impacts reported by survey participants (N = 356), clustered into social, environmental, economic, and energy-production themes, and compared between supporters and opposers of wind farms. The logistic regression indicates significant differences in the number of impacts mentioned between supporters and opposers (Significance levels: *P ≤ 0.05; **P ≤ 0.01; **P ≤ 0.001).

Table D.1, Supplementary material D). No significant difference was found for economic impacts.

We also examined how having prior experience with wind farms is associated with the frequency of impacts associated with the four themes. The model's goodness of fit resulted in a X2(4, N=356) = 49.64, $p < .001$. The results of the logistic regression suggest that people with experience with wind farms tend to mention more social, environmental and economic impacts of wind farms than people without experience, shown here by the relative frequencies of accumulated impacts reported across the four themes by their level of experience (Fig. 5). The mean odds for selecting social impacts were 1.67 (95%CI [01.35,2.09]) times higher, and for environmental impacts were 1.34 (95%CI [1.08, 1.66]) times higher for participants with experience compared to participants without experience with wind farms (full regression results in Table D.2 in Supplementary material D). Notably, the mean odds to report economic impacts were almost double for participants with experience with wind farms (OR= 1.98, 95%CI [1.42, 2.79]). For energy production impacts, no significant differences were detected.

Finally, we conducted a Chi-squared test to determine the association between level of support and level of experience, suggesting that within

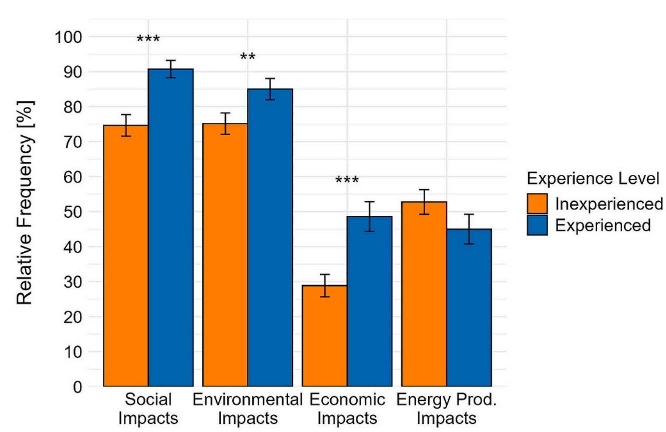

Fig. 5. Relative frequencies of wind farm impacts reported by survey participants (N = 356), clustered into social, environmental, economic, and energy-production themes, and compared between participants with and without experience with wind farms. The logistic regression indicates significant differences in the number of impacts mentioned between experienced and inexperienced participants (Significance levels: *P ≤ 0.05; **P ≤ 0.01; **P ≤ 0.001).

our sample, people who had experience with wind farms are also likely to support wind farms (X2 (1, N=356) = 35.95 and $p < .001$).

Notably, for this examination, we aggregated participants with direct and indirect experience and compared them to participants with no experience with wind farms at all. As direct and indirect experience are likely to manifest differently in participants' perceptions, we included separate logistic regression analyses for participants with direct experience and participants with indirect experience in the supplementary materials tables D.3. and D.4. The results of the separate analysis suggest similar patterns with slight differences between the two groups. The effect might be smaller for indirect experience than for direct experience. Social, environmental and economic impacts still yielded significant results for indirect experience. People with direct experience are more likely to mention social and economic impacts, while environmental impacts did not result in any statistically significant difference. Future research could more systematically examine the differences in perception between participants with direct and indirect experiences with wind farms to determine whether perceptions of the impacts are shaped by the kind of experience.

4. Outlook - The need for an integrated approach to assess the perception of different wind farm impacts

This study captured the variety of wind farm impacts people expect or have experienced across Europe. Participants considered impacts across multiple domains, indicating a broad and interconnected perception of wind farm impacts. Our findings demonstrate that both supporters and opponents of wind farms consider similar impacts but emphasise different themes. Supporters more often mention benefits related to energy production, particularly green energy. Individuals with direct wind farm experience report a wider range of impacts and are more likely to note economic effects. Experience with wind farms was associated with higher levels of support, suggesting that individuals recognising a wider spectrum of impacts may maintain positive attitudes toward wind farms. Our results support case-specific findings from Le Maitre et al. [44], who found experience to be an important determinant for support for wind farms. Participants reported more direct negative than positive impacts, suggesting limited awareness of long-term benefits such as potential compensation schemes or intergenerational gains. This could indicate that these impacts are not salient for people, or they have not yet received sufficient information about the benefits. This points out a relevant shortcoming, as providing information about community benefits was found to increase local support for projects in their development stage [45]. It might also point towards the application of the availability heuristic, as polarisation, social media and clickbait might lead to negative information being more present in media coverage and therefore be more salient [46]. However, support for wind energy remains high in our sample, even though emphasis is placed on the negative effects of wind farms. This suggests that awareness of potential negative effects does not necessarily lead to opposition to the technology. Further, some participants might consider positive impacts, such as sustainable energy, as the objective or purpose of the wind farm, rather than an impact and therefore not formulate it as such. We observed discrepancies between participants' high ratings of literature-based concepts and their open-ended responses. While our assessment of the relevance of literature impacts allows participants to apply their own interpretation and report their subjective assessment, it does not allow us to draw conclusions on the rationale people use to rate the impacts. For instance, climate change was rated highly relevant but seldom mentioned in the open questions. Some impact descriptions from the open question lacked specificity, which could mean that certain participants may face challenges in evaluating or clearly articulating the perceived impacts.

This study serves as an exploratory assessment of perceptions surrounding wind farm impacts with several limitations. Although our sample is not representative of the included countries, we are confident it captures diverse perspectives and experiences through the inclusion of participants from varied backgrounds (see Supplementary Material, Table C.2). Future research adopting a similar approach should further investigate potential confounding factors among the various stakeholder groups. Additionally, we do not provide in-depth descriptions or an exhaustive list of the various perceived impacts. We acknowledge that some context-specific responses may not be generalizable and cannot be considered as a simple explanation for acceptance of wind farms. Rather, this study offers a comprehensive, multidisciplinary examination of diverse perceived wind farm impacts. Nevertheless, we show that the perception or knowledge of impacts directly relates to participants' support for wind energy and their previous experience. We therefore conclude that understanding the mechanisms that ultimately shape acceptance or opposition to wind farms relies on careful consideration of perceptions of wind farm impacts. Furthermore, our research design allowed participants to report their level of acceptance, but not to describe the underlying mechanisms and reasons shaping these self-reported assessments. Future research could therefore further differentiate how perceived impacts relate to both local acceptance and more general attitudes towards wind energy in a country. Our findings suggest that support for wind energy can be strengthened through thorough discussions of perceived impacts and increased citizen exposure to existing projects, though the generalisability of this should be tested in future research. Specifically, perceived wind farm impacts might offer relevant insights when investigated for concrete geographic locations with wind farm development. Future research should focus on elucidating the causal relationships people make among different impact themes, including how they weigh and negotiate trade-offs across diverse impact categories. A mental model approach could be particularly useful in integrating perspectives on these inherently different themes, as demonstrated in studies on climate change risk perception [47] and the energy transition [48,49]. Additionally, there is a need for more context-specific, interdisciplinary research involving a multiplicity of stakeholders throughout the wind farm lifecycle [15,23].

A holistic understanding of stakeholder perceptions, particularly which wind farm impacts matter to people and why, is essential for robust and informed decision-making in wind energy development. This study demonstrates that public perceptions of wind farm impacts are not inherently negative but encompass both positive and negative aspects. This highlights the need for communication strategies that engage transparently with the full range of perceived impacts across different themes. Proactively addressing this spectrum can foster trust and enable more meaningful dialogue with affected communities. A realistic representation of impacts, such as a virtual reality experience on visual and acoustic impacts, can foster support for wind farm projects, particularly for a population that is inexperienced or lacks information about wind energy [50]. An example currently being developed is an online interactive map that provides information on a range of potentials and impacts in Europe in a balanced way [51]. Such an approach contributes to a more integrated understanding of wind farm impacts and supports future research and policymaking on public perception and acceptance, ultimately promoting more inclusive and effective decision-making.

CRediT authorship contribution statement

Leanda Vedder: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Karlijn van den Broek:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Martin Junginger:** Writing – review & editing, Supervision. **Luis Ramirez Camargo:** Writing – review & editing, Visualization, Supervision, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2026.104819.

Data availability

Data will be made available on request.

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